A model-free control strategy for an experimental greenhouse with an application to fault accommodation

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Abstract

Writing down mathematical models of agricultural greenhouses and regulating them via advanced controllers are challenging tasks since strong perturbations, like meteorological variations, have to be taken into account. This is why we are developing here a new model-free control approach and the corresponding "intelligent" controllers, where the need of a "good" model disappears. This setting, which has been introduced quite recently and is easy to implement, is already successful in many engineering domains. Tests on a concrete greenhouse and comparisons with Boolean controllers are reported. They not only demonstrate an excellent climate control, where the reference may be modified in a straightforward way, but also an efficient fault accommodation with respect to the actuators.

Keywords: Agriculture, greenhouse, temperature, hygrometry, model-free control, intelligent proportional controller, fault-tolerant control

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Table 1: Percentage distribution of surfaces for the soilless crop greenhouses in France in 2005

Climate control			
Without	Manual	Automated	Computerized
6 %	7 %	20 %	67 %

1. Introduction

Table 1 in Callais (2006) shows that already a few years ago a large percentage of agricultural greenhouses were computerized. The corresponding automated microclimate regulation should not only improve the production and its quality but also reduce pollution and energy consumption. Most of the existing control approaches, like adaptive control, predictive control, optimal control, stochastic control, nonlinear control, infinite dimensional systems, PIDs, On/Off, or Boolean, control, fuzzy control, neural networks, soft computing, expert systems, ..., have been employed and tested. The literature on the modeling and control of greenhouses is therefore huge. See, *e.g.*,:

- the books by Medjber (2012); Ponce *et al.* (2012); Rodríguez *et al.* (2015); van Straten *et al.* (2010); Urban *et al.* (2010); Von Zabeltitz (2011); and the references therein,
- the papers and memoirs by Aaslyng *et al.* (2005); Arvantis *et al.* (2000); Balmat, Lafont (2003); Bennis *et al.* (2008); Blasco *et al.* (2007); Caponetto *et al.* (2000); Cate, Challa (1984); Critten, Bailey (2002); Cunha *et al.* (1997); Dong *et al.* (2013); Duarte-Galvan *et al.* (2012); El Ghoumari *et al.* (2005); Fourati (2014); Gruber *et al.* (2011); Ioslovich *et al.* (2009); Kimball (1973); Kittas, Batzanas (2010); Lafont, Balmat (2002); Pasgianos *et al.* (2003); Pessel, Balmat (2005); Pessel *et al.* (2009); Piñón *et al.* (2005); Salgado, Cunha (2005); Shamshiri, Wan Ismail (2013); Speetjens *et al.* (2009); Tchamitchian *et al.* (2006); Viard-Gaudin (1981); Zhang (2008); and the references therein.

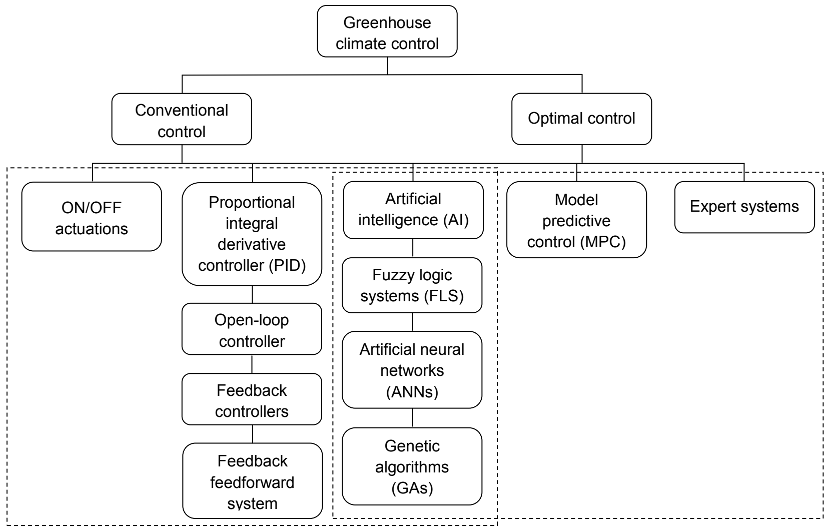

Figure 1: Greenhouse control theories classification in Duarte-Galvan *et al.* (2012)

Let us summarize, perhaps too briefly, some of the various control aspects which were developed in the above references (see, also, Figure 1):

- writing down a "good" model, which is necessarily nonlinear, either via physical laws or via black box identification, leads to most severe calibration and robustness issues, especially with respect to strong weather disturbances, which are impossible to forecast precisely,
- for multi-models appropriate control laws are difficult to synthesize,
- "conventional" PID and On/Off techniques, which preclude any mathematical modeling, are therefore the most popular in industrial greenhouses, although:
  - they are difficult to tune,
  - their performances are far from being entirely satisfactory.

Here, an experimental greenhouse is regulated via a new approach, called *model-free control* (Fliess, Join (2013)), and their corresponding *intelligent* controllers, where:

- any need of a mathematical model disappears,
- the flaws of conventional PID and On/Off techniques vanish.

It should be emphasized that this setting (which is less than ten years old):

- has already been most successfully applied in a number of practical case-studies, which cover a large variety of domains (see the references in Fliess, Join (2013, 2014)),
- is easy to implement (Fliess, Join (2013); Join *et al.* (2013)).

Besides excellent experimental results, a straightforward fault tolerant control with respect to actuators is a quite exciting byproduct. It should be emphasized here that fault accommodation for greenhouse control has unfortunately not been very much investigated until now (see nevertheless Bontsema *et al.* (2011)).

Our paper is organized as follows. Sections 2 and 3 summarize respectively model-free control and actuator fault accommodation. Our experimental greenhouse system and its climate management problem are described in Section 4. Section 5 displays our experimental results with our very simple intelligent controller. Comparisons with a classical Boolean controller are found in Section 6. The efficiency of our method, is further confirmed in Section 7 where the temperature references are modified. Section 8 deals with fault accommodation. Some concluding remarks are provided in Section 9.

When compared to the two first drafts of this work, which appeared in conferences (Lafont *et al.* (2013, 2014)), this paper:

- is proposing a much simpler control synthesis than in Lafont *et al.* (2013),
- gives a much more detailed review of model-free control than in Lafont *et al.* (2013, 2014),
- reports, contrarily to Lafont *et al.* (2013, 2014):
  - the hygrometry control,
  - the time evolution of F in Equation (1).

2. Model-free control and intelligent controllers[1]

2.1. The ultra-local model

For the sake of notational simplicity, let us restrict ourselves to single-input single-output (SISO) systems.[2] The unknown global description of the plant is replaced by the *ultra-local model*:

$$\boxed{\dot{y} = F + \alpha u} \tag{1}$$

where:

- the control and output variables are respectively u and y,
- the derivation order of y is 1 like in most concrete situations,
- $\alpha \in \mathbb{R}$ is chosen by the practitioner such that αu and $\dot{y}$ are of the same magnitude.

The following comments might be useful:

- Equation (1) is only valid during a short time lapse. It must be continuously updated,[3]
- F is estimated via the knowledge of the control and output variables u and y,
- F subsumes not only the unknown structure of the system, which most of the time will be nonlinear, but also of any disturbance.[4]

[1]See Fliess, Join (2013) for more details.

[2]See also Section 5.

[3]The following comparison with computer graphics, which is extracted from Fliess, Join (2013), might be enlightening. Reproducing on a screen a complex plane curve is not achieved via the equations defining that curve but by approximating it with short straight line segments. Equation (1) might be viewed as a kind of analogue of such a short segment.

[4]See also the recent comments by Gao (2014).

Remark 2.1. *The general ultra-local model reads*

$$y^{(\nu)} = F + \alpha u$$

where $y^{(\nu)}$ *is the derivative of order* $\nu \geq 1$ *of* y. *When compared to Equation* (1), *the only concrete case-study where such an extension was until now needed, with* $\nu = 2$, *has been provided by a magnetic bearing (see De Miras* et al. *(2013)). This is explained by a very low friction (see Fliess, Join (2013)).*

2.2. Intelligent controllers

Close the loop with the following *intelligent proportional-integral controller*, or *iPI*,[5]

$$u = -\frac{F - \dot{y}^* + K_P e + K_I \int e}{\alpha} \tag{2}$$

where:

- $e = y - y^\star$ is the tracking error,
- K_P, K_I are the usual tuning gains.

When $K_I = 0$, we obtain *intelligent proportional controller*, or *iP*, which will be employed here:

$$\boxed{u = -\frac{F - \dot{y}^* + K_P e}{\alpha}} \tag{3}$$

Combining Equations (1) and (3) yields:

$$\dot{e} + K_P e = 0$$

where F does not appear anymore. The tuning of K_P is therefore quite straightforward. This is a major benefit when compared to the tuning of "classic" PIDs (see, *e.g.*, Åstrom, Hägglund (2006); O'Dwyer (2009), and the references therein). Note moreover that, according to Section 6.1 in Fliess, Join (2013), our iP is equivalent in some sense to a classic PI controller. The integral term

[5]The term *intelligent* is borrowed from Fliess, Join (2013), and from earlier papers which are cited there.

in the PI controllers explains why steady state errors are avoided here with our iP.

Remark 2.2. *Section 6 in Fliess, Join (2013) extends the above equivalence to classic PIDs and the "intelligent" controllers of Fliess, Join (2013). Two important facts, which were quite mysterious in today's literature, are therefore fully clarified:*

- *the strange ubiquity of PIDs in most diverse engineering situations,*
- *the difficulty of a "good" PID tuning for concrete industrial plants.*

Remark 2.3. *Besides numerous academic comparisons in Fliess, Join (2013), see,* e.g., *Gédouin* et al. *(2011) for a thorough comparison between our intelligent controllers and PIDs for a concrete case-study,* i.e., *the position control of a shape memory alloy active spring. All those comparisons turn out to be in favor of our intelligent controllers.*

Remark 2.4. *Our intelligent controllers are successfully used in an on-off way. This was also the case in Abouaissa* et al. *(2012) for a freeway ramp metering control.*

2.3. Estimation of F

Assume that F in Equation (1) is "well" approximated by a piecewise constant function F_{est}. The estimation techniques below are borrowed from Fliess, Sira-Ramírez (2003, 2008).[6]

2.3.1. First approach

Rewrite then Equation (1) in the operational domain (see, *e.g.*, Yosida (1984)):

$$sY = \frac{\Phi}{s} + \alpha U + y(0)$$

[6]See also the excellent recent book by Sira-Ramírez *et al.* (2014).

where Φ is a constant. We get rid of the initial condition $y(0)$ by multiplying both sides on the left by $\frac{d}{ds}$:

$$Y + s\frac{dY}{ds} = -\frac{\Phi}{s^2} + \alpha\frac{dU}{ds}$$

Noise attenuation is achieved by multiplying both sides on the left by s^{-2}. It yields in the time domain the realtime estimate, thanks to the equivalence between $\frac{d}{ds}$ and the multiplication by $-t$,

$$F_{\text{est}}(t) = -\frac{6}{\tau^3}\int_{t-\tau}^{t} \left[(\tau - 2\sigma)y(\sigma) + \alpha\sigma(\tau - \sigma)u(\sigma)\right] d\sigma$$

where $\tau > 0$ might be quite small. This integral, which is a low pass filter, may of course be replaced in practice by a classic digital filter.

2.3.2. Second approach

Close the loop with the iP (3). It yields:

$$F_{\text{est}}(t) = \frac{1}{\tau}\left[\int_{t-\tau}^{t} (\dot{y}^\star - \alpha u - K_P e)\, d\sigma\right]$$

Remark 2.5. *It should be emphasized that the above estimation of the function F in Equation* (1) *is quite different from model-based parameter identification. This remains valid in a control adaptive setting, where, as stated by,* e.g.*, Landau* et al. *(2011), "one needs to know the dynamic model of the plant to be controlled."*

Remark 2.6. *Implementing our intelligent controllers is easy (see Fliess, Join (2013); Join* et al. *(2013)).*

3. Actuator's fault accommodation

As explained in Figure 2 there are two main ways in order to deal with an actuator fault (see, *e.g.*, Isermann (2011); Noura *et al.* (2009); Shumsky *et al.* (2011)):

1. the first one is self-tuning, or fault accommodation. It relies on an on-line control law that preserves the main performances, while some minor parts may slightly deteriorate,

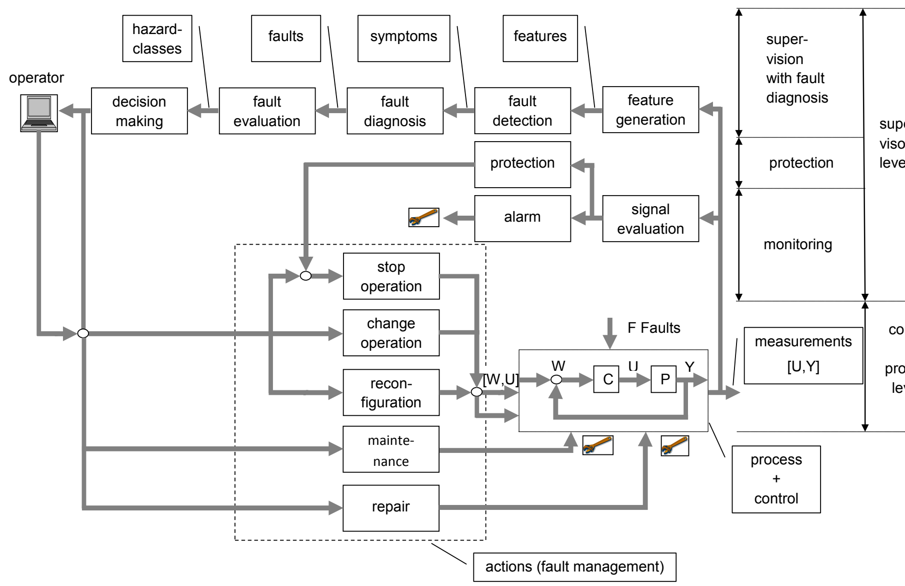

Figure 2: A supervision structure

2. the second one is self-organization where faulty components are replaced.

We only consider here fault accommodation. The computations below are adapted from Fliess, Join (2013).

Express the actuator fault via

$$u_r = u\,(1-\beta) \tag{4}$$

where:

- β, $0 < \beta < 1$, is the loss of efficiency of the actuator,
- u_r is the true control variable.

The two following cases are not considered:

- $\beta = 0$ means that there is no fault,
- $\beta = 1$ implies that the control does not act anymore.

Then Equation (1) becomes

$$\dot{y} = \bar{F} + \alpha u$$

where

$$\bar{F} = F - \alpha\beta u$$

The fault accommodation is then achieved by estimating $\bar{F}$ as in Section 2.3.

Remark 3.1. *It is obvious that β does not need to be:*

- *a constant and may be time-varying,*
- *known in order to carry on the above computations.*

Remark 3.2. *For model-based diagnosis, estimation techniques stemming from Fliess, Sira-Ramírez (2003, 2008) have already lead to quite important advances. See,* e.g.*, Fliess* et al. *(2004, 2008); Kiltz* et al. *(2014); Villagra* et al. *(2011a,b).*

4. Greenhouse climate management

Figure 3 shows our experimental plastic greenhouse which is manufactured by the French company *Richel*. Its area is equal to 80 m^2. It is the property of the *Laboratoire des Sciences de l'Information et des Systèmes* (*LSIS*), to which the first three authors belong. This laboratory is located at the *Université de Toulon* in the south of France. Our experimental greenhouse is controlled by a microcomputer and interfaced with the FieldPoint FP-2000 network module developed by the American company *National Instruments Corporation*. The FP-2000 network module is associated with two analog input modules (FP-AI-110, FP-AI-111), for the acquisition, and two relay output modules (FP-RLY-420), for the control. The acquisition and control system is developed with the *LabView* language. The sampling period is equal to 1 minute. The inside air temperature and the humidity are controlled.

4.1. Description of the system

The greenhouse is a multi-input and multi-output (MIMO) system which is equipped with several sensors and actuators (Figure 4).

There are:

Figure 3: Our experimental greenhouse system

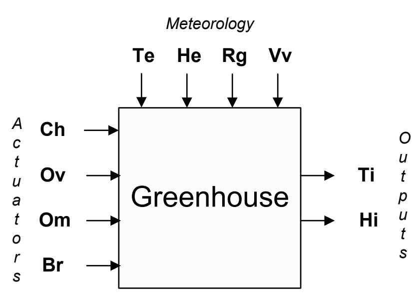

Figure 4: System variables

- four actuators:
    1. Heating (thermal power 58 kw): Ch ($Boolean$),
    2. Opening (50 % max): Ov (%),
    3. Shade: Om (%),
    4. Fog system: Br ($Boolean$).
- four meteorological disturbance sensors:
    1. External temperature: Te (^oC),
    2. External hygrometry: He (%),
    3. Solar Radiation: Rg (W/m^2),
    4. Wind speed: Vv (km/h).
- two internal climate sensors:
    1. Internal temperature: Ti (^oC),
    2. Internal hygrometry: Hi (%).

This system is nonstationary and strongly disturbed. Figures 5 and 6 show, for instance, quite high solar radiation and external temperature during the 24^{th} September 2014. These meteorological conditions have a significant effect on the inside greenhouse climate which are clear on Figure 7.

4.2. Climate management problem

The management of the greenhouse climate aims to maintain simultaneously a set of climatic factors such as the temperature, the hygrometry, and the rate of CO_2[7] close to their respective references. In our greenhouse, the temperature and the hygrometry managements are treated together, because these two quantities are strongly correlated:

- the heating has a dehumidifier effect,

[7]This last rate is not available on our greenhouse.

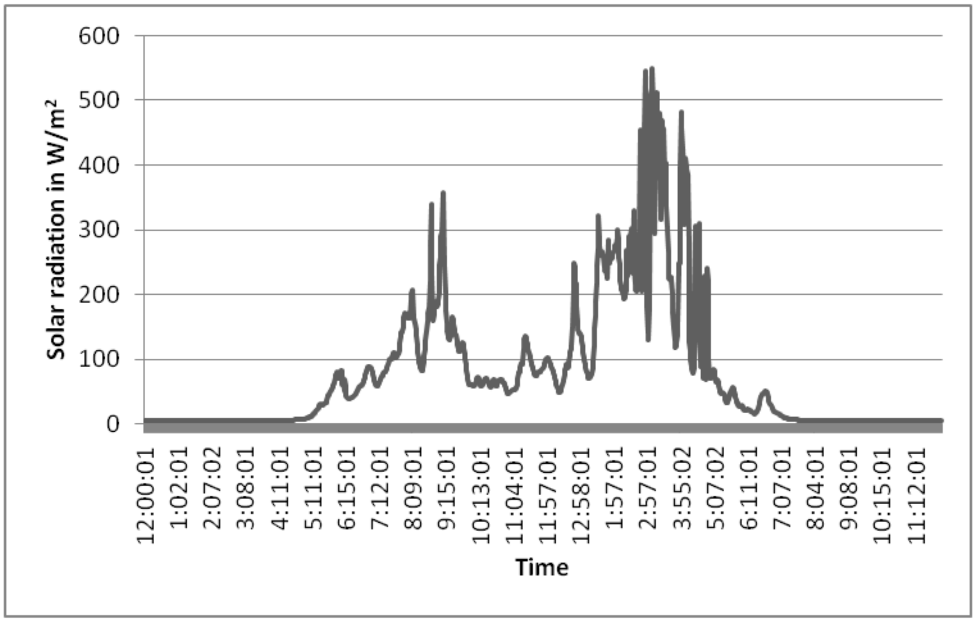

Figure 5: Solar radiation during the 24^{th} September, 2014

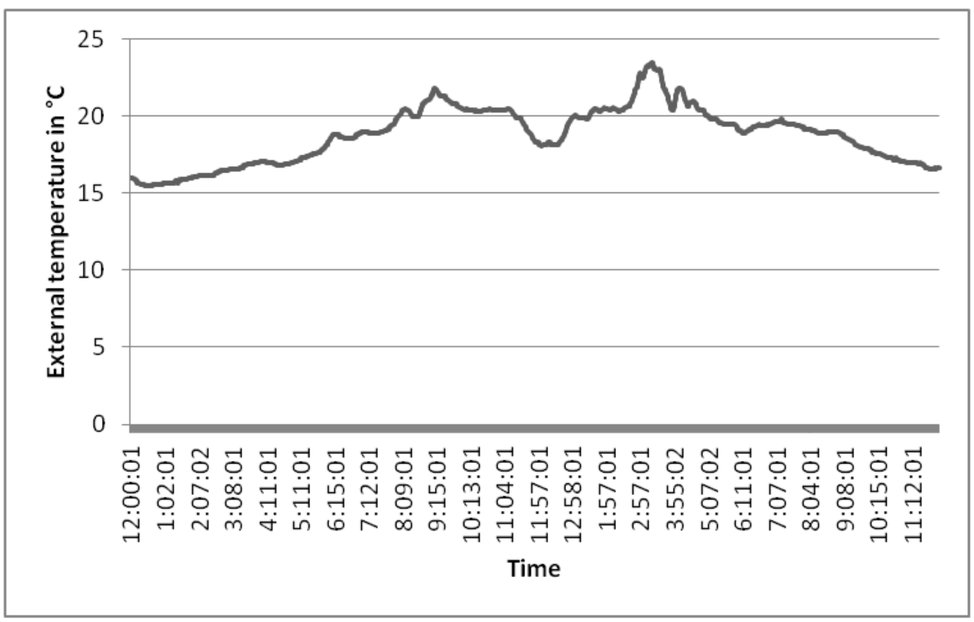

Figure 6: External temperature during the 24^{th} September, 2014

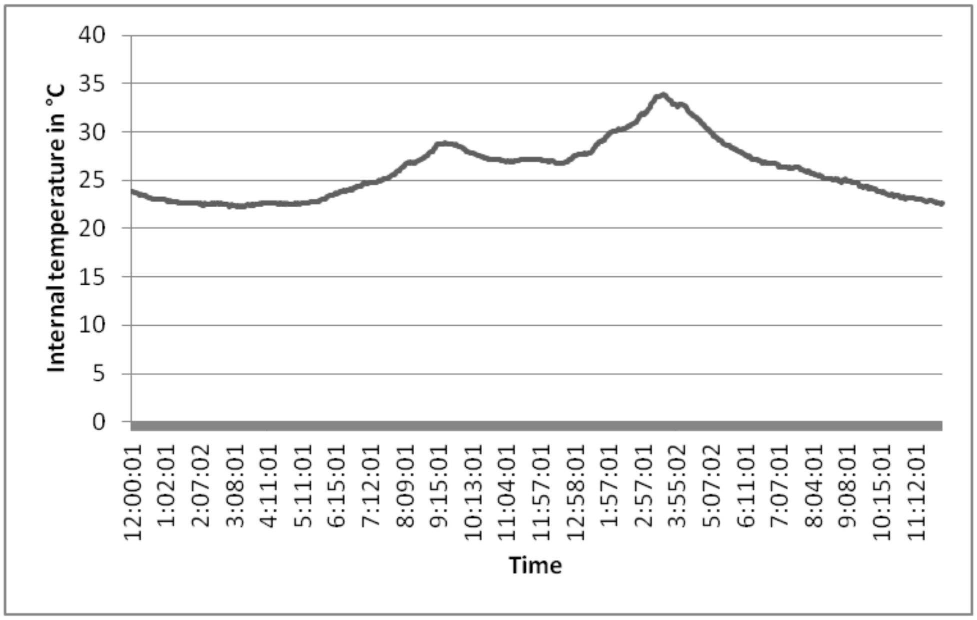

Figure 7: Internal temperature during the 24^{th} September, 2014

- the opening system has a cooling and dehumidifier effect,
- the fog system has a cooling effect.

Controlling the temperature and the hygrometry is therefore of utmost importance. In order to choose the suitable output references, two main strategies exist.

4.2.1. The classic strategy

Growers refer to their knowledge to fix the hygrometry and temperature references.

Hygrometry reference. There is no real recommendations by species. It appears nevertheless that:

- for the multiplication phase, the hygrometry must be greater than 80 %,
- for the growth phase, the reference is comprised between 60 and 80 %,

- for the tomato, the reference is rather comprised between 50 and 70 %.

Let us mention some other advices. Avoid:

- condensations,
- a humidity level close to saturation (100 %),
- a humidity level below 40 % for seedlings,
- absolutely a hygrometry below 20 %.

Temperature reference. Table 2 displays references among suppliers, which are based on the species.[8] Observe that the difficulties for tuning an efficient controller may be attributed to the following causes:

- various references:
  - in a day,
  - according to the species.
- system parameter variations according to the plant growth.

4.2.2. The innovative strategy

Tchamitchian *et al.* (2006) developped a decision-making system, called SERRISTE. It generates daily climate reference for greenhouse grown tomatoes. This system, which uses the knowledge of advisers or expert growers to manage the greenhouse climate, can be encapsulated and exploited in a reference determination software. This tool provides daily references to growers taking into account various objectives such as the phytosanitary prevention, the energetic cost, the growth of the crop, ... The system uses data such as seasons, crop stages, the daily period (divided into three subperiods), the characteristics of

[8]Temperatures are expressed in Celsius degrees.

Table 2: Temperature reference (see (Urban *et al.*, 2010))

Species	Night reference	Day reference	Remarks
Aubergine	21^oC	22^oC	During 4 weeks after the plant.
	19^oC	21^oC	To the end
Cucumber	21^oC	23^oC	During 4 weeks After the plant.
	20^oC	22^oC	During the next 6 weeks.
	19^oC	21^oC	To the end.
Lettuce	10^oC	10^oC	During 2 weeks After the plant.
	6^oC	12^oC	To the end.
Pepper	20^oC	23^oC	During 3 weeks after the plant.
	18^oC	22^oC	To the end.
Tomato	20^oC	20^oC	During 1 week after the plant.
	18.5^oC	19.5^oC	During the next 5 weeks.
	17.5^oC	18.5^oC	To the end.
Azalea	$18/21^oC$	$>18^oC$	
Chrysanthemum	17^oC	18^oC	
Gerbera	$13/15^oC$		
Antirrhinum	$10/11^oC$		
Carnation	$12/13^oC$	18^oC	
Rosebush	17^oC	21^oC	

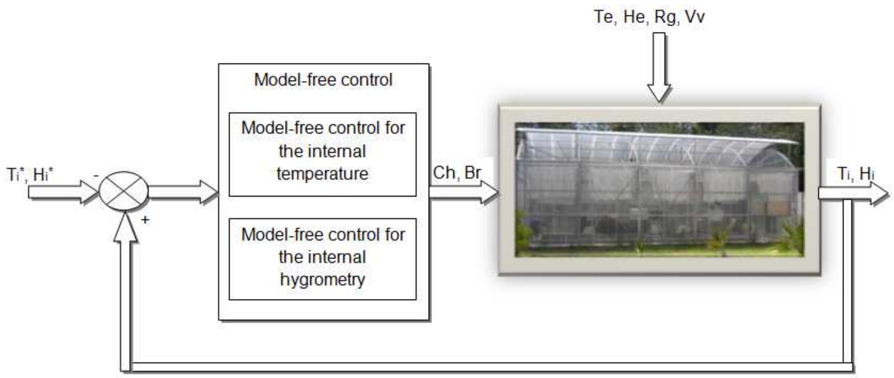

Figure 8: Block diagram of the experimental setup

the greenhouse system (location, heating system, ...) and dynamic informations (past climate, crop state, ...). Sections 4.2.1 and 4.2.2 show the reference changes according to the time of day or the plant growth. This is another justification for our model-free control.

5. Intelligent P control of the experimental greenhouse

An iP (3) is implemented for the regulation of the temperature and the hygrometry, which turn out to be naturally decoupled in our model-free setting (Figure 8).[9]

We are estimating F via the technique sketched in Section 2.3.2.

5.1. Estimation of F

The estimation $F_{\text{est}}^{\text{temp}}$ is given by

$$F_{\text{est}}^{\text{temp}} = \frac{1}{\delta} \int_{T-\delta}^{T} \left(-\alpha Ch + \dot{T}i^{*} - K_P e_{Ti} \right) d\tau \tag{5}$$

where:

[9]Our restriction in Section 2 to detail only SISO systems is therefore fully justified. See also Menhour *et al.* (2013) for the behavior of a vehicle.

Table 3: Setting values

Variable	Value
δ	6 minutes
α	1
K_P	2

- $e_{Ti} = Ti - Ti^*$ is the temperature tracking error,
- $\dot{Ti}^*$ is the reference derivative of Ti (when internal temperature reference is constant then $\dot{Ti}^*$ is equal to 0).

and $F_{\text{est}}^{\text{hygro}}$ by

$$F_{\text{est}}^{\text{hygro}} = \frac{1}{\delta}\int_{T-\delta}^{T}\left(-\alpha Br + \dot{Hi}^* - K_P e_{Hi}\right)d\tau \tag{6}$$

where:

- $e_{Hi} = Hi - Hi^*$ is the temperature tracking error,
- $\dot{Hi}^*$ is the reference derivative of Hi (when internal hygrometry reference is constant then $\dot{Hi}^*$ is equal to 0).

5.2. Setting values and results

The controllers Ch and Br are deduced from Equations (1), (3) and (5). They are *Pulse Width Modulation* (PWM) controllers. The rules given in Section 2.1 yield Table 3, which displays the same values for the two controllers.

The reference output is 18^oC for the temperature with a tolerance equal to 0.5^oC and 60 % for the hygrometry. The temperature sensors PT100 sensors, of class A, with an accuracy of $\pm\ 0.3^oC$. A tolerance of 0.5^oC would be realistic since, for many species, the difference between night and day reference is equal to 1^oC, as shown in Table 2. We want to differentiate night and day. Sensors with an accuracy of $\pm\ 0.3^oC$ permit to take into account a tolerance equal to 0.5^oC. Simulations last 12 hours, from 8:00 p.m. until 8:00 a.m. We choose

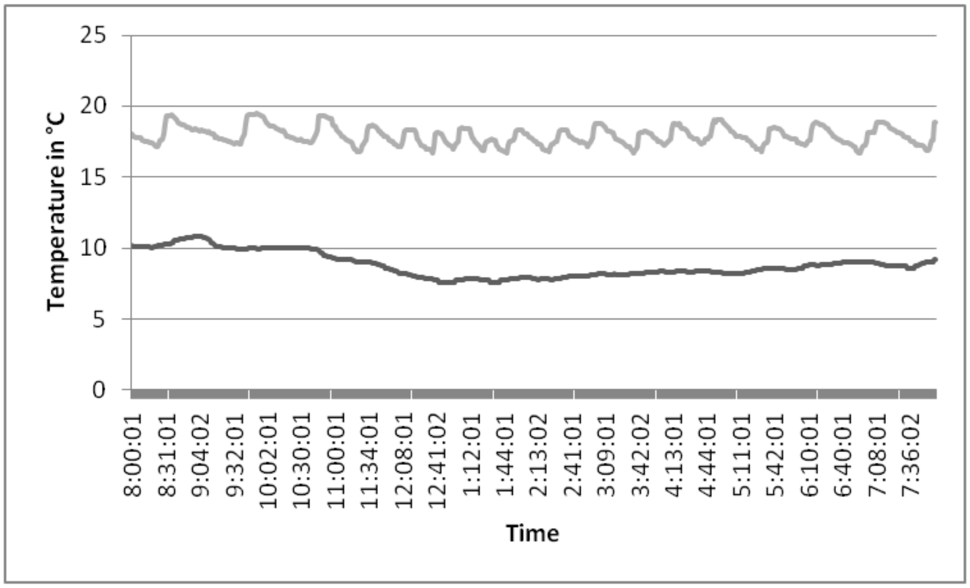

Figure 9: Temperature with model-free control (Te: black line - Ti: grey line)

the night in order to compare the obtained results with Boolean control (see Section 6) in similar weather conditions.

Figure 9 shows the internal/external temperature evolution during the night of 20-21 February 2014. Figure 10 shows the heating control sequences. Observe that the heating control allows at the internal temperature T_i to be close to its reference output. Figure 11 shows the evolution of F_{est}^{temp} during this night.

Figure 12 shows the internal hygrometry evolution during the night of 20-21 February 2014. Figure 13 shows the sequences for the fog control. We can observe that, at 4:00 a.m., the internal hygrometry H_i is also above the reference output: it started to rain. So, the fog system Br stops. Otherwise, the internal hygrometry H_i is close to this reference output.

Table 4 shows the mean and the variance of the error between T_i and the output reference of T_i and between H_i and the reference output of H_i.

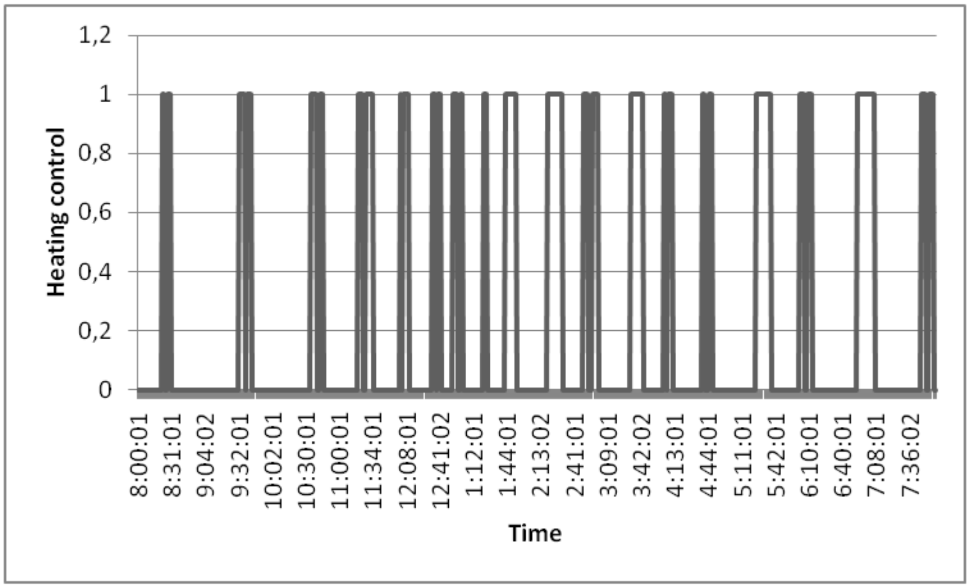

Figure 10: Heating control with model-free control

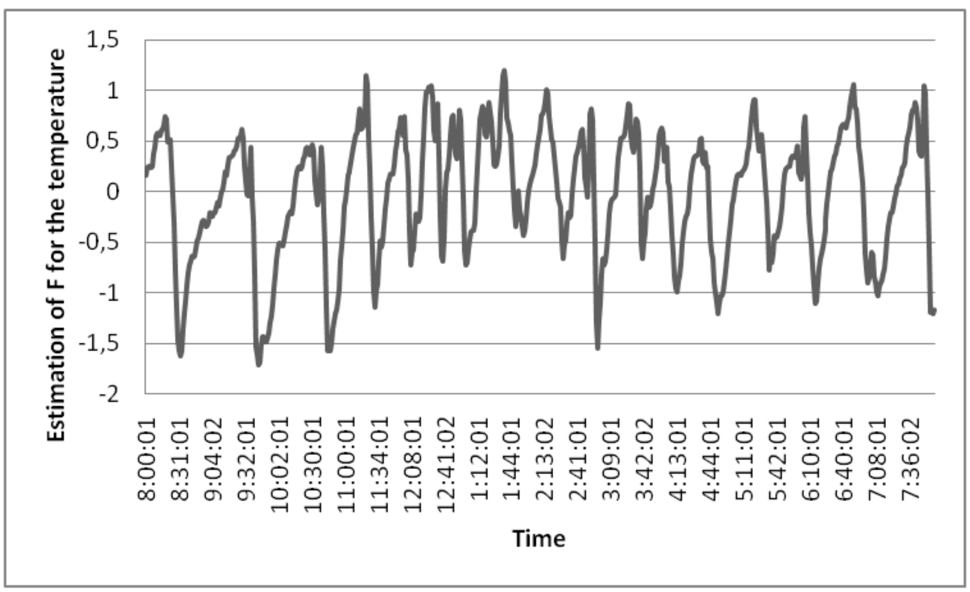

Figure 11: Evolution of F_{est}^{temp}

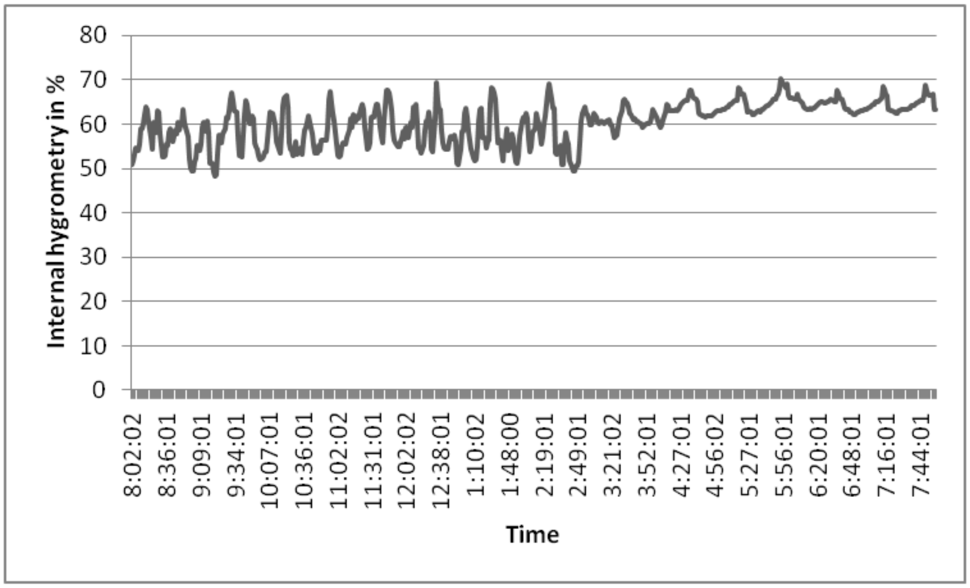

Figure 12: Internal hygrometry with model-free control

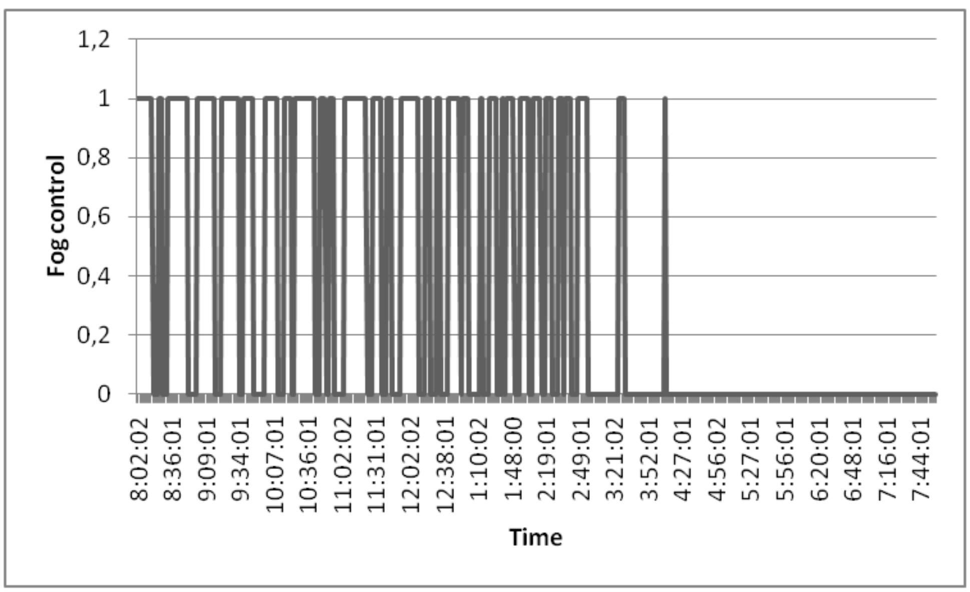

Figure 13: Fog control with model-free control

Table 4: Results evaluation for the model-free control

Output error	mean	variance
e_{T_i}	-0.1^oC	0.4^oC
e_{H_i}	0.4 %	21.8 %

Table 5: Results evaluation with a classic Boolean control

Output error	mean	variance
e_{T_i}	0.8^oC	0.7^oC
e_{H_i}	5.0 %	71.7 %

6. Comparison between iP and classic Boolean control

A classic Boolean control law with thresholds is employed for the comparisons. This type of technique is quite often utilized in agriculture. Experiments have been carried on during two different nights, *i.e.*, 20 -21 and 21-22 February 2014, respectively for the model-free and boolean settings. The temperature reference output is 18^oC with a tolerance equal to 0.5^oC, as in Section 5. For the hygrometry, a dehumidification reference should be selected. The fog control is periodic (3 minutes on and 27 minutes off) whatever the internal hygrometry. This Boolean control of the humidity is based on the grower rules. The dehumidification reference allows to set the desired maximum hygrometry inside the greenhouse. In this test, we choose 60 %.

Figure 14 and 15 show respectively results for the internal temperature and for the heating control during the night of 21-22 February 2014.

Figure 16 shows the internal hygrometry evolution during the night of 21-22 February 2014. Figure 17 shows the sequences for the fog control.

Table 5 shows the mean and the variance of the error between T_i and the output reference of T_i for this night.

Tables 4 and 5 demonstrate that our model-free control strategy behaves

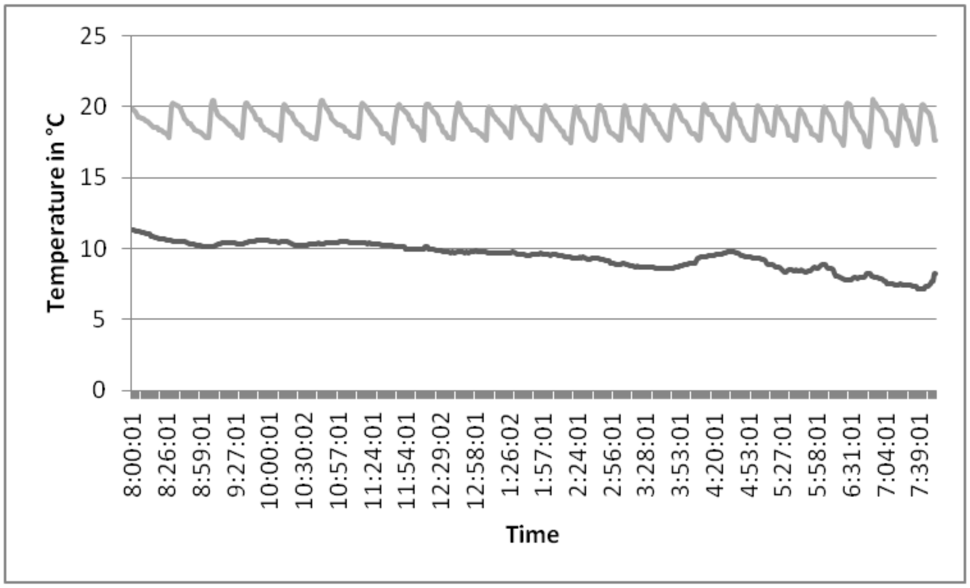

Figure 14: Temperature with a Boolean controller (Te: Black line - Ti: Grey line)

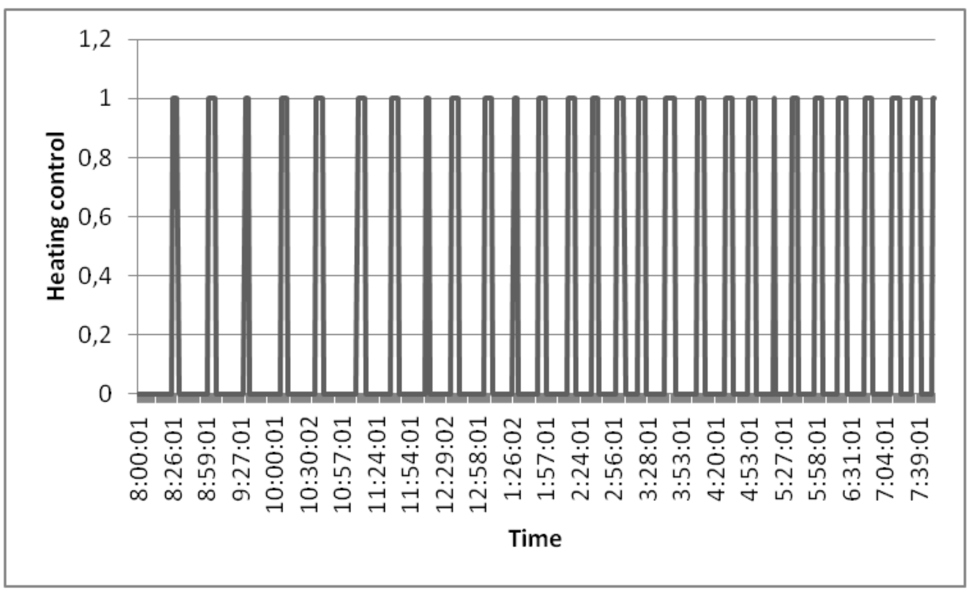

Figure 15: Heating control with a Boolean controller

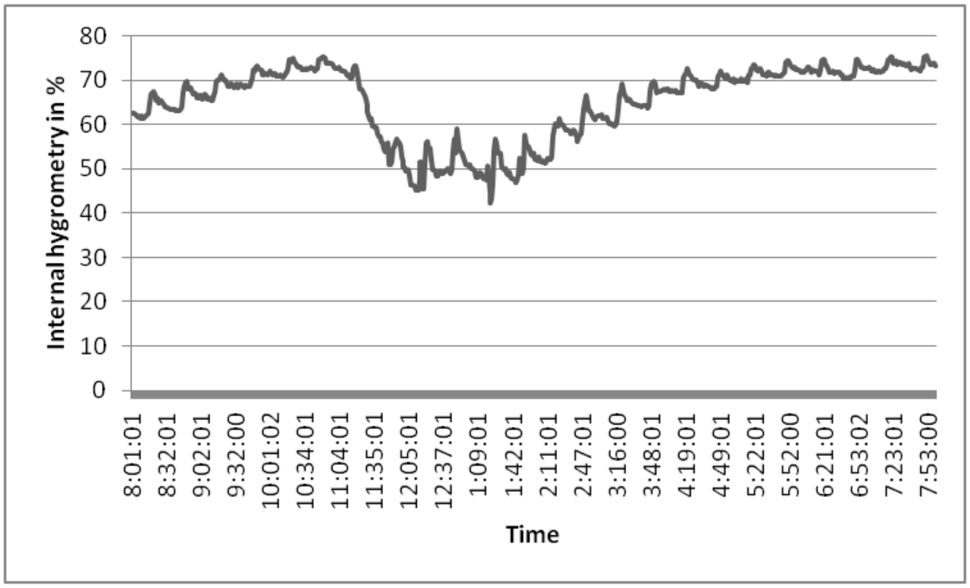

Figure 16: Internal hygrometry with a Boolean controller

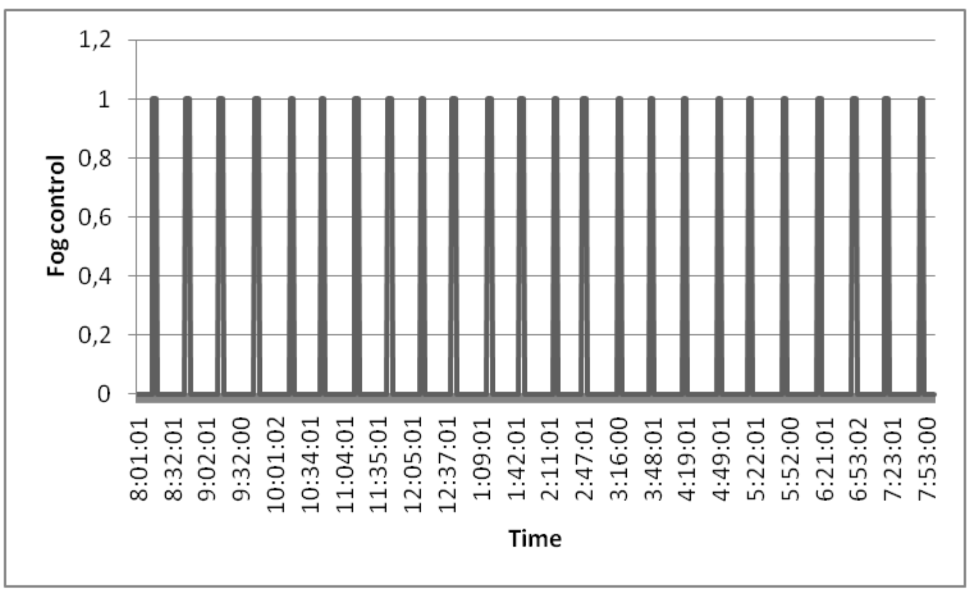

Figure 17: Fog control with a Boolean controller

Table 6: Comparisons of the energy

Actuator	Model-free control	Classical Boolean control
$Heat$	143 min	145 min

better than its Boolean counterpart. Let us emphasize two more points:

- as already explained in Section 4, one of the goals of climate control is to consume as little energy as possible. Table 6 shows that the heating is on only during 20 % of the time with the model-free setting. The model-free controller is therefore much cheaper,
- for a given operating time, the model-free control ensures a better tracking of the reference signal.

7. Reference change

Figure 18 shows results for the internal temperature with a reference change (without any modification of the parameter values of the iP controller). We regulate the greenhouse with the temperature reference output equal to 20^oC during the night of 11-12 February 2014. Figure 19 represents the heating control.

Results for the internal temperature with an other reference change are displayed on Figure 20. We regulate the greenhouse with the temperature reference output equal to 16^oC during the night of 17-18 February 2014. Figure 21 represents the heating control.

We can observe that model-free control results are always *good* since the internal temperature follow to the reference output (see Table 7). As sketched in Section 4.2 and presented in Table 2, this is a most significant advance.

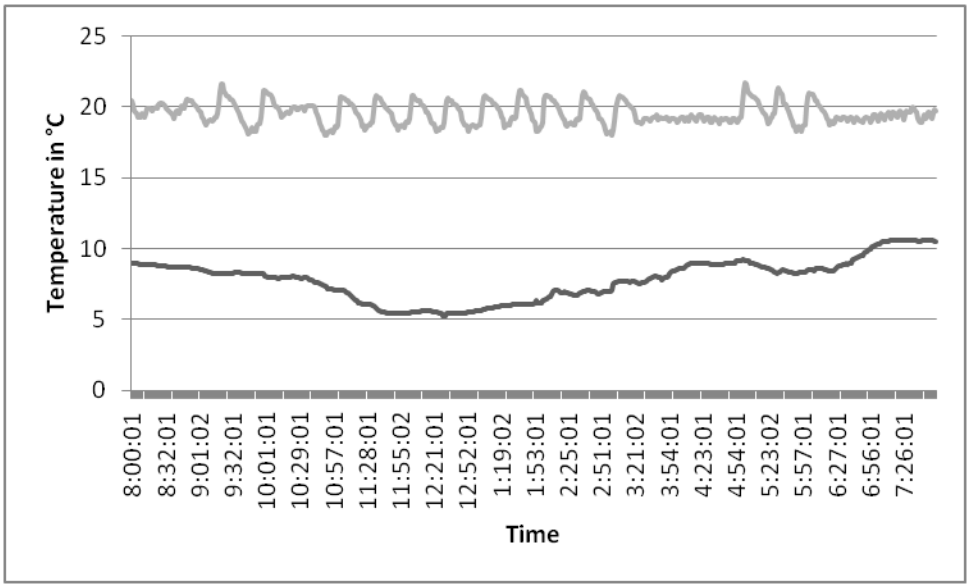

Figure 18: Temperature with model-free control (Te: Black line - Ti: Grey line)

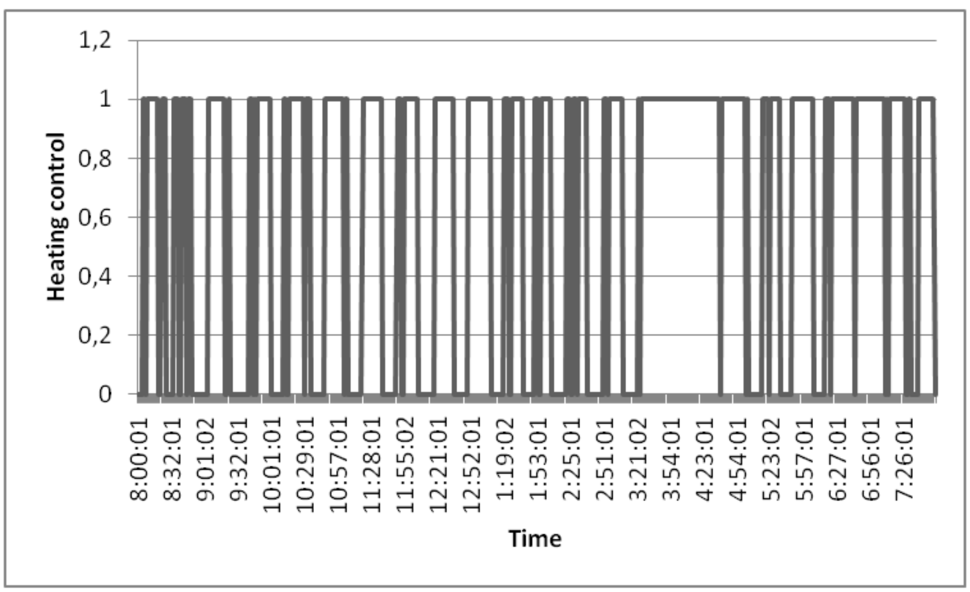

Figure 19: Heating control with model-free control

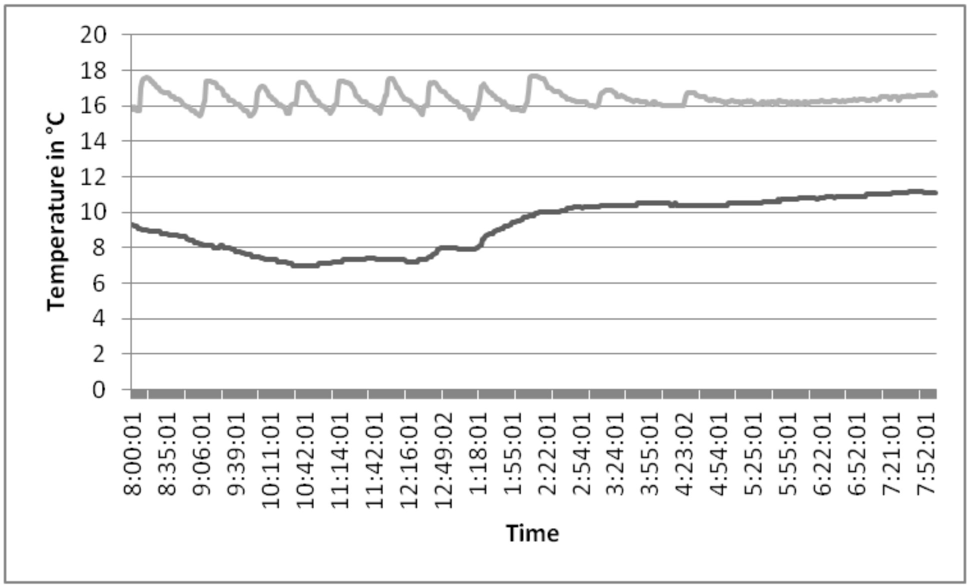

Figure 20: Temperature with model-free control (Te: Black line - Ti: Grey line)

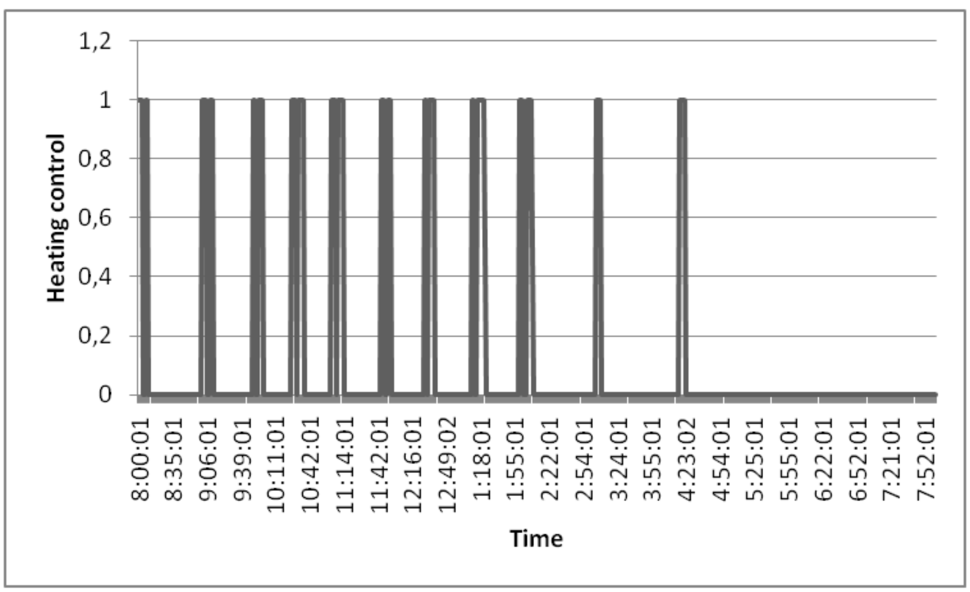

Figure 21: Heating control with model-free control

Table 7: Results evaluation for the model-free control

Output error	mean	variance
e_{T_i} for $Ti^* = 20^oC$	-0.4^oC	0.6^oC
e_{T_i} for $Ti^* = 16^oC$	0.4^oC	0.2^oC

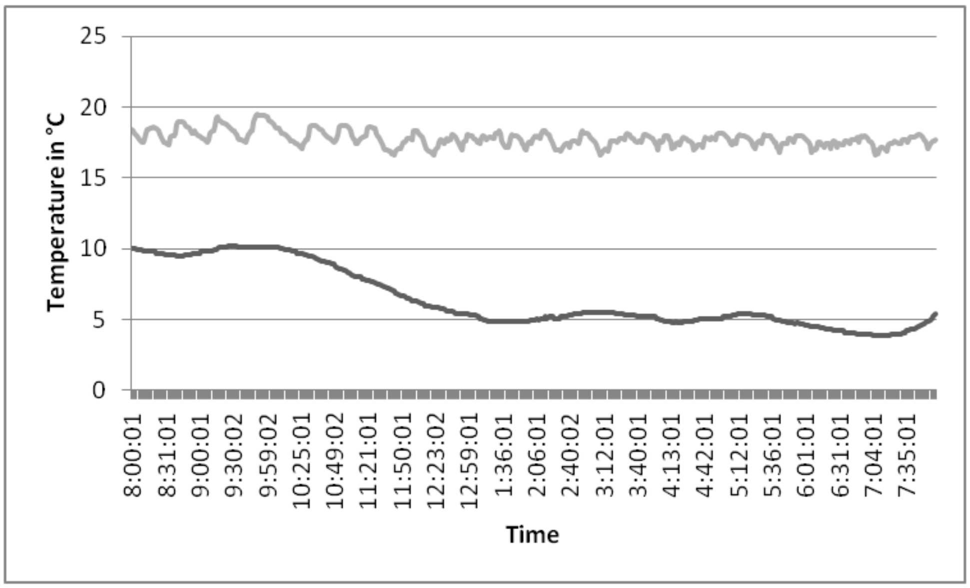

Figure 22: Temperature with model-free control (Te: Black line - Ti: Grey line)

8. Fault accommodation

An actuator fault can be described by Equation (4). An actuator fault on the heating control is simulated by a loss of efficiency equal to 50 %. Figure 22 shows results for the internal temperature with the temperature reference output equal to 18^oC during the night of 12-13 February 2014. Figure 23 demonstrates the accommodation ability of the heating control. The output temperature remains moreover very close of the internal temperature reference value.

Another actuator fault confirms the previous facts. Figure 24 shows the results for the internal temperature with the temperature reference output equal to 18^oC during the night of 13-14 February 2014, with a loss of efficiency equal to

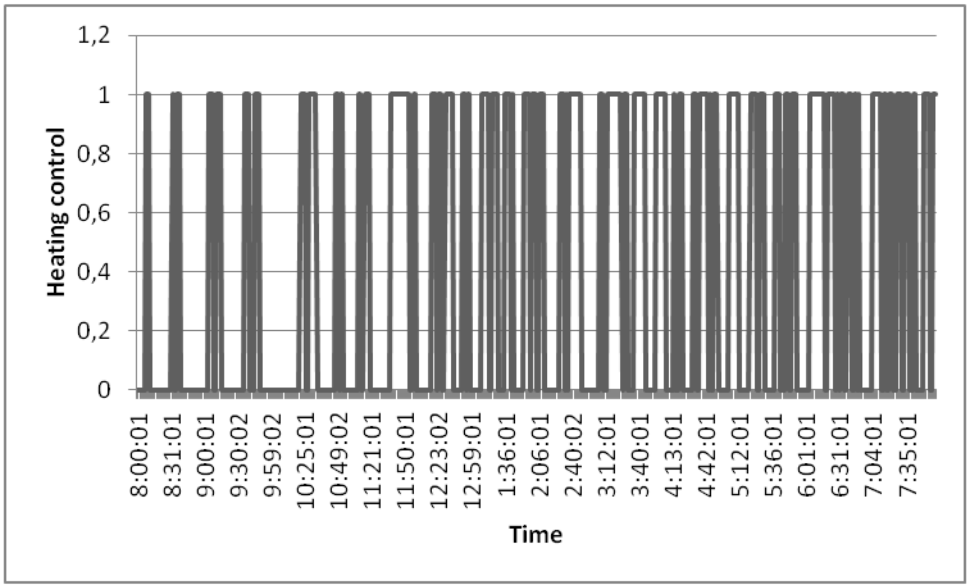

Figure 23: Heating control with model-free control

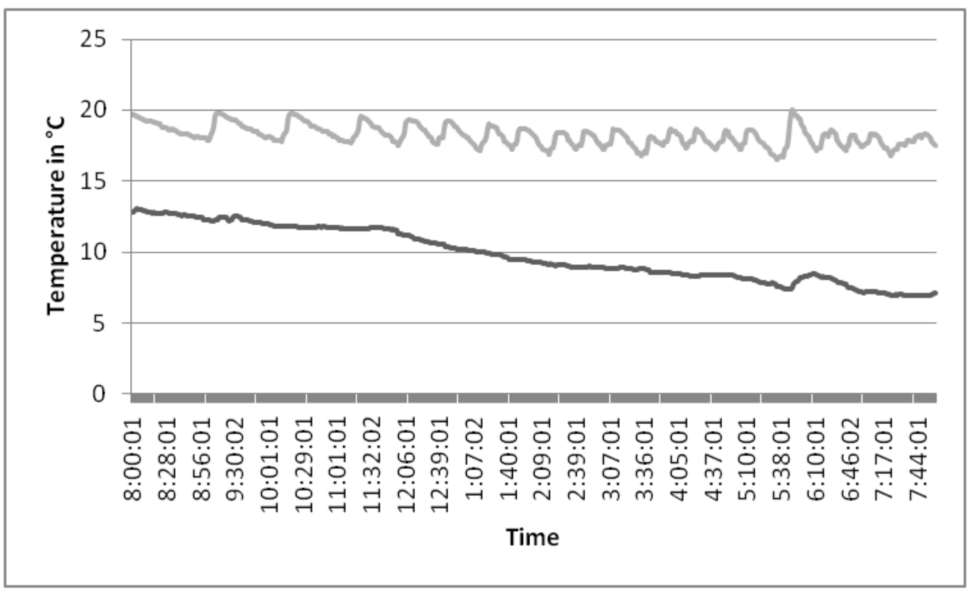

Figure 24: Temperature with model-free control (Te: Black line - Ti: Grey line)

25 %. The performances displayed by Figure 25 and Table 8 are again excellent.

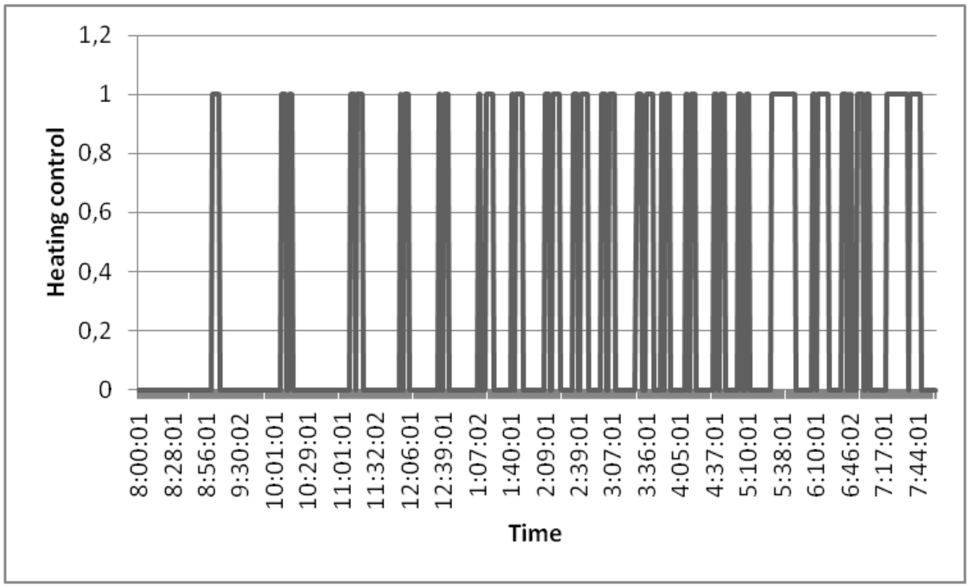

Figure 25: Heating control with model-free control

Table 8: Results evaluation for the model-free control

Output error	mean	variance
e_{T_i} with $\beta = 50$ %	-0.2^oC	0.3^oC
e_{T_i} with $\beta = 25$ %	0.2^oC	0.5^oC

9. Conclusion

Our successful model-free control strategy and its fault-tolerant capabilities will be further developed by taking advantage of technologically more advanced greenhouse systems. Let us mention here, among many other possibilities, a regulation of the CO_2 rate. Further comparisons with various other feedback synthesis techniques should also be investigated. We also hope that similar techniques might be useful in more or less analogous domains like air-conditioning in buildings (see, *e.g.*, Liu *et al.* (2013)). Data mining techniques will also be considered (see, *e.g.*, Hou *et al.* (2006)).

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